



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT OF 6kW VARIABLE POWER SUPPLY LEADING TO
KNOWLEDGE EXTRACTION FOR POWER ELECTRONIC
DESIGN AID SYSTEM DATABASE**

YOUSIF ABBAKER ADAM

FK 1999 21

**DEVELOPMENT OF 6kW VARIABLE POWER SUPPLY LEADING TO
KNOWLEDGE EXTRACTION FOR POWER ELECTRONIC
DESIGN AID SYSTEM DATABASE**

By

YOUSIF ABBAKER ADAM

**Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of
Science in the Faculty of Engineering
Universiti Putra Malaysia**

November 1999



*Dedicated to
My
Parents, Wife, Sisters and Son*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirements for the Degree of Master of Science.

**DEVELOPMENT OF 6 kW VARIABLE POWER SUPPLY LEADING TO
KNOWLEDGE EXTRACTION FOR POWER ELECTRONIC
DESIGN AID SYSTEM DATABASE**

By

YOUSIF ABBAKER ADAM

November 1999

Chairman: Norman Bin Mariun, Ph.D., PEng.

Faculty : Engineering

Expert systems are starting to play an important role in this era of knowledge. As we are moving from information age to knowledge age; management and organisation of human expertise will have a great impact in all aspect of life in terms of time saving and money. This project is targeted to feed the expert system with the knowledge that is extracted during the process of design and development of a power supply. The design of the power supply is the major part of the work while the extraction of knowledge comes after.

The power supply circuit is composed of three major stages; the input power AC to DC conversion circuit, the Buck converter power circuit that is controlled by PWM signal, and the control circuit which includes the logic, isolation and driving circuits.

Switching technique is employed based on duty cycle control by which the different outputs is obtained. Insulated Gate Bipolar Transistor (IGBT) is used as a power switch protected by snubber circuit. A negative feedback is employed to maintain constant output. The power supply design is simulated using PSpice and the hardware circuit is then built and tested.

The complete design of the power supply is achieved and as the expected results are obtained leading to the knowledge extraction process during the power supply development, by which this work contributes to the Power Electronic Design Aid System database (PEDAS).

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains.

**PEMBANGUNAN PEMBEKAL KUASA BOLEHUBAH 6kW KEARAH
MEMPEROLEHI PENGETAHUAN BAGI PANGKALAN DATA
SISTEM REKABENTUK LITAR ELEKTRONIK KUASA**

Oleh

YOUSIF ABBAKER ADAM

November 1999

Pengerusi : Norman bin Mariun, Ph.D., PEng.

Fakulti : Kejuruteraan

Sistem Pakar memainkan peranan penting dalam era pengetahuan masa kini. Perubahan kepakaran manusia daripada era maklumat kepada pengurusan pengetahuan dan organisasi akan memberikan kesan yang baik dalam semua aspek kehidupan dalam ertikata menjimatkan masa dan wang. Projek ini disasarkan untuk memberi Sistem Pakar dengan pengetahuan yang diperolehi semasa proses rekabentuk dan membangunkan bekalan kuasa. Rekabentuk bekalan kuasa merupakan bahagian utama projek ini yang mana pengetahuan akan datang kemudian.

Litar bekalan kuasa terdiri daripada tiga peringkat utama; kuasa masukkan AC kepada litar penukar DC, litar kuasa penukar 'Buck' yang dikawal oleh isyarat PWM, dan litar kawalan termasuk logik, pemisahan dan litar pemacu.

Penggunaan teknik pensuisan berasaskan kepada litar kawalan kerja dengan keluaran berbeza diperolehi. 'Transistor Dwikutub Get Tertebat (IGBT)'

digunakan sebagai suis kuasa yang dilindungi oleh litar 'Snubber'. Tindakbalas negatif diambil untuk menetapkan keluaran kekal. Rekabentuk bekalan kuasa disimulasikan dengan menggunakan perisian 'Pspice' dan kemudian dari itu litar perkakasan dibina serta diuji.

Rekabentuk bekalan kuasa yang lengkap dicapai dan hasil/keputusan yang dijangka diperolehi yang membdehkan proses pengambilan pengetahuan semasa pembangunan bekalan kuasa, dengan itu projek ini menyumbang pembangunan pengkalan Data Sistem Rekabentuk Elektronik Kuasa (PEDAS).

ACKNOWLEDGEMENTS

Verily those who say, “ Our Lord is Allah,” And remain firm (On that Path)-
On them shall be no fear, Nor shall they grieve.

First and foremost my thanks to Allah S.W.T who gave me power and help to complete this work which I hope will contribute to the welfare of our nation.

I would like at this juncture to express my deepest appreciation and gratitude to my kind supervisor Ir. Dr. Norman Bin Mariun, for his encouragement and effective guidance throughout the research period.

Special thanks and appreciation extended to the members of my supervisory committee Dr. Ishak B. Aris, and Dr. Mohd Yazid for their most appreciable help and assistance. My thanks and gratitude extended to Dr. Abdrahman Ramli and Dr. Mahmud Hassan for their cooperation and help.

My thanks also extended to the staff at Graduate School Office for their help and cooperation. My appreciation to all individuals at the Department of Electrical and Electronic Engineering and Computer Lab, who have been cooperative.

My thanks and appreciation to all individuals and colleagues at the CASC research centre for their help and suggestions during the research work.

I certify that an Examination Committee met on 26th November 1999 to conduct the final examination of Yousif Abbaker Adam on his Master of Science thesis entitled “Development of 6kW Variable Power Supply Leading to Knowledge Extraction for Power Electronic Design Aid System Database” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. The Committee Members for the candidate are as follows:

RAHMAN BIN WAGIRAN, M.Sc.

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

NORMAN BIN MARIUN, Ph.D., PEng.

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ISHAK BIN ARIS, Ph.D.

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Md. Yazid Mohd Saman, Ph.D.

Lecturer
Fakulti Sains Komputer &
Teknologi Maklumat
Universiti Putra Malaysia
(Ahli, Jawatankuasa Penyeliaan)



MOHD. GHAZALI MOHAYIDIN, Ph.D.

Professor/Deputy Dean of Graduate School
Universiti Putra Malaysia

Date: **31 DEC 1999**

This thesis submitted to the Senate of Universiti Putra Malaysia and was accepted as fulfilment of the requirements for the degree of Master of Science.



KAMIS AWANG, Ph.D.

Associate Professor/Dean of Graduate School
Universiti Putra Malaysia

Date: **4 JAN 2000**

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I declare that this thesis has not been previously or concurrently submitted for any other degree at UPM or any other institutions.



(Yousif Abbaker Adam)

Date: December 30, 1999

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL SHEETS	viii
DECLARATION FORM	xiii
LIST OF TABLES	xvi
LIST OF FIGURES	xvii
LIST OF PLATES	xx
LIST OF ABBRIVIATIONS	xxi
CHAPTER	
I INTRODUCTION	1
Electronic Power Supplies Development	1
Knowledge Base Expert System Development	2
Objective of Thesis	3
The Importance of the Work for Knowledge Base Expert System	3
Thesis Layout	4
II LITERATURE REVIEW	5
Power Supply System	5
Classification of Regulated Power Supplies	8
Linear Power Supplies	9
Switching Regulators	14
Switch-Mode Power Supply Topologies	16
Buck Converter Operation Modes	19
Thermal Effect in Power Semiconductor	29
Sources of Power Loss in a Semiconductor Device	29
Semiconductor Thermal Characteristics	30
Overview on Stability and Control Techniques of a Buck Converter	34
Pulse Width Modulation (PWM) Applications	38
Power Factor Correction Techniques	40
Filters and Noise Reduction in Power Converters	43
Knowledge Base Expert System (KBES)	45
Application of Expert Systems during the Knowledge Age	50
Architecture of an Expert System Shell	52
Building an Expert System	57
Knowledge Representation and Inferencing	61
Knowledge Encoding	64

III	MATERIALS AND METHODS	65
	Introduction	65
	Materials Used	66
	Proposed Hardware Layout and Elements Description	67
	Methods	70
	Pulse Width Modulation Technique	70
	Buck Converter Elements Design	73
	Gate Drive Techniques	75
	Bootstrap Driving Technique	79
	Snubber Circuits	85
	Feedback Loop Design	89
	Heatsink Design Calculations	90
	Knowledge Extraction Method	95
IV	RESULTS AND DISCUSSION	96
	Simulation Results	96
	Hardware Results	100
	Discussion	108
	Power Electronics Design Aid System (PEDAS) Structure	115
V	CONCLUSION AND FUTURE RECOMMENDATIONS	118
	REFERENCES	122
	APPENDICES	
A	Components Data Sheets	126
B	Simulation Program Netlist	148
VITA		166

LIST OF TABLES

Table		Page
1	Driving Circuits Methods	78
2	Output Voltage Ripple	108
3	Output Current Ripple	109
4	Voltage and Current Measurements	110

LIST OF FIGURES

Figure		Page
1	Power Supply Concept	6
2	Classification of Regulated Power Supplies	8
3	Zener Diode Regulator	9
4	Power Transistor Regulator	10
5	Three-Terminal Regulator Circuits	11
6	Three-Terminal Adjustable Regulator	12
7	High Current Regulator	13
8	Switching-Mode Regulator	14
9	Buck Converter	17
10	Boost Converter	17
11	Buck-Boost Converter	17
12	Cuk Converter	18
13	Resonant Converter	18
14	Ideal Converter Output Waveform	19
15	Waveforms for Step Down Switch-Mode Regulator	20
16	Inductor Current Waveform	21
17	Capacitor Current	22
18	Inductor Current: Boundary of Discontinuous Conduction	25
19	Buck Converter Discontinuous Conduction	26
20	FET-BJT Darlington for Power Switching	28
21	Device-Based Model for IGBT	28

22	Equivalent Circuit of a Semiconductor Device Mounted on a Heatsink	31
23	Power Pulses	33
24	Shell Architecture	54
25	Proposed Power Supply Block Diagram	69
26	PWM Functional Diagram and Waveforms	72
27	Power MOSFET in High Side Configuration	77
28	Bootstrap Circuit	79
29	Turn-off Snubber Circuit	86
30	Turn-on Snubber Circuit	87
31	Combined Snubber Circuit	87
32	Feedback-Closed Loop	89
33	Electrical Analog of Heat Transfer	91
34	Power Semiconductor Switch Current and Voltage Waveforms	93
35	The Rectified Smoothed DC	96
36	Simulation Results for 10V-Output Voltage	97
37	Simulation Results for 20V-Output Voltage	98
38	Simulation Results for 30V-Output Voltage	98
39	Simulation Results for 40V-Output Voltage	99
40	The Complete Switch Mode Power Supply Wiring Diagram	101
41	Pulsed Emitter Voltage to Produce 10V Output	103
42	Pulsed Emitter Voltage to Produce 20V Output	103
43	Pulsed Emitter Voltage to Produce 30V Output	104

44	Pulsed Emitter Voltage to Produce 40V Output	104
45	Pulsed Emitter Voltage to Produce 50V Output	105
46	Pulsed Emitter Voltage to Produce 60V Output	105
47	Saw-Tooth Generated by the PWM Chip TL494	106
48	PWM Chip Output and Optocoupler Output Waveforms	106
49	Gate Signal Waveform and the Corresponding Output Voltage	107
50	Voltage Ripple against Duty Cycle	108
51	Current Ripple against Duty Cycle	109
52	Efficiency Against Output Voltage	110
53	Bode Plot of the Closed Loop System	111
54	PEDAS General architecture	115
55	PEDAS Main Frame	116
56	PEDAS Circuit List Menu	116
57	PEDAS Application Menu	117
58	PEDAS Help Menu	117

LIST OF PLATES

Plate		Page
1	Hardware Components	102
2	Hardware Building and Testing	102

LIST OF ABBREVIATIONS

BJT	Bipolar Junction Transistor
C	Collector
D	Duty Cycle
E	Emitter
f	Frequency
f_c	Corner Frequency
f_s	Switching Frequency
FM	Frequency Modulation
G	Gate
GTO	Gate turn-off thyristor
IGBT	Insulated Gate Bipolar Transistor
J	Junction Area
J_c	Dissipated Conduction Energy
L	General Inductance Symbol
MCT	MOS Controlled Thyristor
MOSFET	Metal-Oxide Silicon Field Effect Transistor
P_c	Conduction Power Loss (W)
P_s	Switching Power Loss (W)
P_t	Total Power Dissipation (W)
PWM	Pulse Width Modulation

Q	Charge (Coulomb)
R	General Symbol for Electrical Resistance (OHMS)
R_{c-a}	Case to Ambient Thermal Resistance
R_{h-a}	Heatsink to Ambient Thermal Resistance
R_{J-a}	Junction to Ambient Thermal Resistance
R_{θ}	Thermal Resistance ($^{\circ}\text{C/W}$)
R_{CS}	Thermal Resistance ($^{\circ}\text{C/W}$)
R_{JC}	Thermal Resistance from Junction to Case ($^{\circ}\text{C/W}$)
R_{SA}	Thermal Resistance from Heatsink to Ambient ($^{\circ}\text{C/W}$)
S	Heatsink
SDR	Sequential Discharge Rectification
SMPS	Switch Mode Power Supplies
T	General Symbol for the Temperature ($^{\circ}\text{C/W}$)
T_A	Ambient temperature ($^{\circ}\text{C}$)
T_C	Case Temperature ($^{\circ}\text{C}$)
T_J	Junction Temperature ($^{\circ}\text{C}$)
V	General Symbol for the Voltage Measured in (Volts)
VAR	Volt-Ampere Reactive
ZCS	Zero Current Switching
ZVS	Zero Voltage Switching
τ	Time Constant
Ω	Ohm Symbol
ξ	Damping Factor

CHAPTER I

INTRODUCTION

Electronic Power Supplies Development

Electronic power supplies are most often charged with the task of altering, controlling or regulating electrical power. All electronic and electrical devices need a power supply in order to operate. Usually a dc supply voltage is delivered to the device and a dc current was drawn which depends on the absorbed power.

Switch mode regulators are the most popular due to their fairly high efficiency and compact size and a switch mode regulator is used in place of a linear voltage regulator at relatively high output. Switch-mode regulators overcome the drawbacks of linear regulators. They are more efficient and tend to have an efficiency of 80% or more. As well they can be packaged in a fraction of the size of linear regulators (Danel, W. *et al.*, 1995).

Switch-mode power supplies can step-up or step-down the input voltage. In this design step down power supply is needed. The design of the power supply was governed by the certain specifications to be met. The power supply required in this work is used for sludge treatment system.

In this power supply, six output voltages were required therefore; buck converter topology was chosen.

Knowledge Base Expert System Development

Expert systems are the most practical application of AI today. An expert system is a computer program that emulates the behaviour of a human expert in a well-specified, narrowly defined domain of knowledge (Medsker, *et al.*, 1994). The aim of an expert system is to reproduce the behaviour of a human expert, thus performing an intellectual task in a specific field (Gondran, 1986).

Expert systems have three major components. The dialog structure is the user interface that allows the user to interact with the expert system to obtain results and query the system. The inference engine houses the control strategies for generating hypotheses to arrive at a solution. The knowledge base is a set of facts and heuristics for the task at hand used to describe expert system.

Present problem areas where expert systems have been successfully built were: Interpretation, prediction, diagnosis, fault isolation, design, planning, monitoring, debugging, repair, scheduling, instruction, control, analysis, maintenance, configuration and targeting (i.e., Resource allocation).

Objective of Thesis

This thesis has two objectives to be achieved at the end of the project which are:

- The first objective of this project is to design 6kW power supply that can provide the load with variable output voltage varies from 10 to 60V with a maximum current of 100A.
- The second objective of this thesis is to contribute with knowledge and experience that is acquired during the power supply development and feed it to the Power Electronic Design Aid System (PEDAS), developed by the department research group.

The Importance of the Work for Knowledge Base Expert System (KBES)

The successful production of an expert system depends, ultimately, on two individuals or group of individuals; the expert in the field and the knowledge engineer who translates the expert's knowledge into computer software. The knowledge facts and experience gained during the development of power supply was extracted and managed by a knowledge engineer that translates it into computer software. The importance of this work comes in providing the Power Electronics Design Aid System (PEDAS) with the knowledge acquired during power supply developments. The contribution will be on the circuit database of PEDAS system.

Thesis Layout

This thesis consists of five chapters. Chapter I gives a brief introduction to power supply concept and expert systems. Chapter II is devoted to literature and what others have done in this area. Chapter III describes the methodology and materials and the detailed design calculations used in the design. In Chapter IV the results of the simulation and the hardware is shown and discussed, as well as the knowledge extracted from the work. Finally, Chapter V concludes the thesis and recommends future work that can be carried out.

CHAPTER II

LITERATURE REVIEW

Power Supply System

All electronic devices need a power supply in order to operate. Usually a dc supply voltage is delivered to the device and a dc current is taken by it, which depends on the absorbed power. There are only two possible power sources the energy can be taken from: dc batteries and the 50Hz (60Hz) mains. The energy sources of such a nature that electrical perturbation and faults can occur at the delivery point (transient over-voltages, lightening and so on), while the electronic equipment is so delicate that no supply voltage perturbations can be withstood. Moreover, some electronic loads (that is, any electronic equipment supplied by the power supply) themselves cause perturbations (e.g. electric motors and their electronic drives). So power sources need to be protected against them in-order to prevent noise and disturbances to nearby equipment and systems. Hence the power supply must be able to perform the following basic tasks:

- To deliver suitable dc voltages to electronic equipment and systems (loads).
- To decouple the load from the line (or vice versa) in order to prevent any electrical interaction between them.